or less limited areas elevated the State average much above a representative value, thereby giving large departures from the normal and correspondingly small computed yield.

To overcome the difficulties presented by such abnormal conditions, it is believed that in correlations of this character, especially for limited areas and for regions where the summer rainfall frequently occurs in excessive amounts, some method of considering for such excessive falls only that portion that is actually absorbed by the soil, so far as this can be ascertained, should be devised. While it may not be practicable to ascertain these proportions definitely, yet by actual measurement of the water content of the soil at frequent intervals, or by measuring this content before and after rainfalls of varying intensities when runoff occurs, the relation of intensity of fall to runoff could probably be approximately determined. Also, it probably would be feasible to actually measure the runoff for selected limited areas where drainage is effected at a single point, by measuring

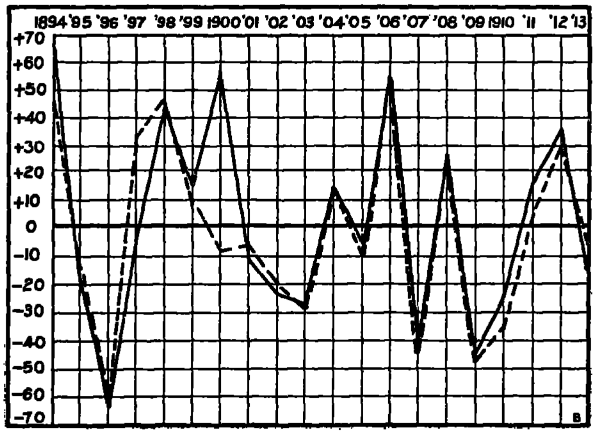

FIG. 9.—The solid line shows the actual departures of yield from the average, expressed in pounds per acre.
The broken line shows the values computed by the application of equation (4) to the departures given in Table 3.

the actual discharge at that point and reducing this to a uniform equivalent of water depth over the entire area. Again, an approximate relation might be established by careful, direct, or personal observations of soil condition and approximate runoff for falls of varying intensities, and the knowledge thus acquired could be utilized to advantage in compiling precipitation data for correlating purposes, as most original records indicate the time of beginning and ending of each rain and the total fall recorded. While only the approximate relation between intensity and runoff could be obtained by this last method, unquestionably it would afford better values of rainfall for correlating purposes than are obtained by accepting the recorded totals, irrespective of whether the entire amount was retained by the soil and utilized in the development of the plants, or a large proportion lost by runoff.

RELATION OF CLIMATE TO PLANT GROWTH IN MARYLAND.

By FORMAN T. MCLEAN.

[Dated: Johns Hopkins University, Baltimore, Md., Mar. 17, 1915.]

INTRODUCTION.

More and more attention is being paid to the relation between climatic conditions and plant growth by students of agriculture, forestry, and climatology. Progress in plant physiology and in agriculture, ecology, and forestry has made it quite clear that the growth of plants is definitely related to the nature of the environmental conditions. This principle has been most successfully applied to studies bearing on irrigation, cultivation, the use of fertilizers, etc. Regarding the relations between the plant and its environment above the soil, however, very little has yet been accomplished. These surroundings of the plant above the soil are the conditions usually termed climatic, and they have been very thoroughly studied by climatologists, but climatological study has seldom had plant relations as its main aim. Similarly, comparative studies of plant phenomena, such as growth, respiration, photosynthesis, and seed production, have not usually been carried out with the idea of relating them directly to climate. It is thus not at all surprising that the data of climatology and those of plant ecology have not been very satisfactorily correlated.

It therefore appears desirable to attack this problem of the climatic relations of plants by methods which are especially planned to bring out, as far as may be, possible correlations between the plant processes on the one hand and climatic conditions on the other. The work here to be considered is a preliminary and rather tentative attempt in this direction. It was carried on under the auspices of the Maryland State Weather Service, to the director of which, Prof. William Bullock Clark, the general project owes its beginning. The work was under the immediate direction of Prof. Burton E. Livingston, to whom the writer most gratefully acknowledges his indebtedness for his suggestions and assistance both in planning the study and in presenting the results. The author also expresses his thanks to Dr. Oliver L. Fassig, of the United States Weather Bureau, for valued assistance in presenting and interpreting the weather data; and his most sincere appreciation to the eight cooperative weather observers, who not only very kindly permitted us to use their private grounds for the experiment plots, but also kept special records in addition to the regular weather observations. We mention with deepest regret the loss of one of the observers, Mr. J. S. Harris, of Coleman, Md. The other observers who assisted in this study are Prof. A. F. Galbreath, Darlington, Md; Mr. J. H. Lawson, Monrovia, Md.; Mr. D. P. Oswald, Chewsville, Md.; President H. J. Patterson, College Park, Md.; Mr. H. Shreve, Easton, Md.; Mr. J. R. Stewart, Princess Anne, Md.; and Mr. R. E. Weber, Oakland, Md.

The previous work of the Maryland State Weather Service exemplifies the statement made above that ecological and climatic studies have usually been made quite independently of one another. "The Climate and Weather of Baltimore," by Oliver L. Fassig, and the "Climatology of Maryland," by Mr. F. J. Walz, represent very complete studies of the climate of the State, and Dr. Forrest Shreve's "Plant Life of Maryland" represents a corresponding study of the distribution of types of vegetation. The fact that Maryland has received such thorough and careful attention from these two points of view makes it a particularly suitable area for comparative work on the problem before us.

The study here reported was begun in the summer of 1914, and the work of the first season was devoted largely to perfecting and testing methods, so that this paper will deal primarily with methods of investigation and of interpreting results.

It was planned to bring out three sorts of relations between plant growth and environment: (1) The effect of local influences of climatic conditions due to differences in topography, altitude, soil, and exposure; (2) the effects of seasonal influences, as between spring, midsummer, and autumn; and (3) the effects of other influences which are nonperiodic in character and unrelated to either location or season. For the comparison of plant growth and climatic conditions in different parts of the region nine cooperative Weather Bureau stations were selected, four near the shores of Chesapeake Bay and five inland, distributed from the coastal plain to the Allegheny plateau.

METHODS.

It was planned to carry the experiment through the entire frostless season, in order to ascertain the march of plant growth and of climatic conditions throughout one period of active plant growth. The last occurrence of killing frost in spring is about April 15 along the shores of Chesapeake Bay, while at the summit of the Alleghenies it is about May 15.[1] There were, however, delays in securing and installing the necessary equipment, so that the first experimental plantings at the nine stations here employed were not made until the first week in May. Thus no plant records were secured for the first three weeks of the frostless season at the coast stations, but at the other stations the season begins about May 1 or later, so that the first plantings were quite early enough to precede the beginning of the normal frostless season at these latter stations. The observations were continued until the occurrence of killing frost in autumn, at each station.

In order to compare the growth of plants to climatic conditions in different localities, it is necessary that the plants studied in each place shall be similar, both in their hereditary tendencies and in their general physiological condition at the beginning of the experiment. Therefore it is not possible to use the general rate of growth of field crops, in any two localities for any given time period, as an indication of the relations existing between plant growth and the climatic conditions at these stations. The seed from which the field crops were started would probably be of different strains, quite unlike in their response to external conditions and, even if the seed used were the same in both places, the plants would almost surely be different, due to differences in nonclimatic factors of the environment. Furthermore, it is practically impossible to find soils in two widely separated localities which are alike, either in physical character or in fertility. For these and other reasons, pot cultures were used in this study.

Plants of selected strains of wheat, maize, soy bean, and Windsor bean (*Vicia faba*, L.) were employed. The plants were grown in 6-inch pots. One pot culture of each species was started in each locality, approximately every two weeks, and each culture was continued for four weeks. Thus the culture periods overlapped, so there was always left a corresponding culture but two weeks old at the time each culture four weeks old was harvested. The average growth of all of the plants in a culture was used in each case, as a measure of the growth rate; this tended to overcome errors which otherwise might have arisen from individual variations of the plants.

The soil used was the same in all cultures, being of the type classified as Norfolk sand by Bonsteel.[2] It was all obtained from a single locality, near the railway station at College Park, Md. It is a moderately fine sand, with a water-retaining power of 43 per cent, by the Hilgard test.[3] The top soil was removed from a small area to a depth of 6 inches and was thoroughly mixed and sifted. It was placed in sacks and shipped to the different stations, where it was stored in air-dry condition, in covered water-tight cans, until used. Special precautions were taken so that the soils would be as nearly alike as possible, in both texture and condition, at the beginning of all cultures. By keeping it dry and isolating it from the surrounding soil it was, in a measure, prevented from becoming greatly modified by any chemical or biological agencies peculiar to the different locailties. The cultures were each of too short duration to admit of very great modification of the soil during the duration of any single culture, due to such special local influences.

Having thus provided soil of approximately uniform properties for use in the different localities, the next important step was to put it into the same physical condition in all cultures, and to have it all in such condition that it would well retain its structure through the course of a test lasting one month, while exposed to varying conditions of rain, evaporation, and sunshine. The best soil condition for plant growth has generally been demonstrated by agricultural experimenters to be one of loose tilth. Unfortunately, however, such an ideal condition can not be uniformly maintained in soils that are exposed to the weather. Every rain packs the soil more or less, and heavy ones completely saturate it. Therefore each pot of soil here used was completely saturated and allowed to settle before planting the seeds, thus being brought into a condition which, while probably not the most favorable one for plant growth, was still approximately uniform for all cultures at the start and was not greatly modified during the course of any of the experiments. To prevent too great drying between rains, porous-cup auto-irrigators[4] were used to supply moisture to the pots. As here employed, the instrument consisted of two porous clay cups (of the common form furnished by the "Plant World") joined to each other and to the water reservoir by glass tubes. The cups were vertical in the 6-inch pots so that their tops were level with the soil surface and were so arranged as to supply water to the soil under a pressure of less than an atmosphere. The difference between the pressure upon the water in the cup and that in the soil was overcome by the capillary attraction of the water films in the soil. In all the experiments of the past season the reservoir stood at a lower level than the pots, so that when it was full the water level was 14 inches below the soil surface.

By this arrangement the soil moisture in the pots was maintained at a minimum of approximately from 10 to 13 per cent, calculated on the basis of the dry weight of the soil, a condition rather too moist than too dry for the best growth of the plants. The soil of the cultures often showed a moisture content immediately after rains as high as 23 per cent, which was the approximate maximum water-retaining power of the 6-inch columns of soil in the pots, but it never was allowed to become very dry between rains.

The pots were plunged to such a depth that their soil surface was level with the surrounding soil, in order that the soil temperature in the cultures should approximate

[1] A very full discussion of the length of the frostless season in Maryland is given in **Fassig, Oliver L.**, The period of safe plant growth in Maryland and Delaware. Mo. WEATHER REV., 1914, **42**: 152-158.

[2] **Bonsteel, Jay A.**, The soils of Prince George's County. Baltimore, 1911. (Maryland Geological Survey publ.).

[3] **Hilgard, E. W.**, Soils, their formation, properties, and composition. New York, 1911. p. 209.

[4] **Livingston, B. E.**, A method for controlling plant moisture. Plant world, 1906, **11**: 39-40.

Hawkins, Lon A., The porous clay cup for the automatic watering of plants. Plant world, 1910, **13**: 220-227.

Transeau, E. N., Apparatus for studying comparative transpiration. Bot. gaz., 1911, **52**: 54-60.

that of the soil around them. The culture soil was isolated from the surrounding soil by waterproofing the pots on the outside, but this coating became leaky before the end of the month. The entrance of soil water from without and of dissolved salts, could not have been great in any case, however, for the soil inside the pots was always much moister than the surrounding soil; thus any water movement through the walls of the pots should have been outward rather than in the opposite direction. These matters of soil and soil moisture require somewhat detailed attention, for these two factors appear very frequently to be the most influential ones in determining plant growth in this region. They must be at least partially controlled before the effects of other factors upon culture plants may be studied with any hope of satisfactory results. Of course it is to be remembered that in controlling soil moisture one of the direct effects of the factors of rainfall and evaporation was modified.

Four climatic factors were here considered—rainfall, evaporation, temperature, and sunshine. The records of temperature and rainfall were obtained from the observations of the cooperative Weather Bureau observers, the cultures being located close to the stations. The average air temperature during each experiment was computed by the formula ½ (max. + min.), the self-recording thermometers being read daily at sunset. The rainfall measurements were summed for the experimental periods.

The sunshine data were obtained from the instrumental record of the nearest regular Weather Bureau station. Those of Washington, D. C., and Baltimore, Md., were combined and the average of the sunshine of these two stations was used to represent the general condition in the region around Easton, Md., and the records of Elkins, W. Va., were similarly used to represent the sunshine in the Oakland region. These were used in preference to the local observers' estimates of clear and cloudy days, because they are much more detailed and less affected by differences in individual judgment. The great similarity between the two kinds of records for the same general area seems to justify this application of the instrumental records of sunshine at a few stations to an extended region. These instrumental records are only approximations of the effectiveness of sunshine in promoting plant growth, as the Marvin instrument (Marvin sunshine recorder) begins to record sunshine when the intensity is above a certain arbitrary minimum, and records no sunshine when the intensity is below this. The instrument thus takes no account of the absolute intensity of the total solar radiation or of the relative intensities of the different wave-lengths of light, both of which are important in their effects upon plant processes. The records of sunshine used, however, are the best that are available at present. The number of hours of sunshine is used as a basis for comparison in preference to the percentage of possible sunshine, because the number of hours of possible sunshine, upon the basis on which the latter is computed, is a variable quantity. Thus a certain percentage of possible sunshine in June indicates a much longer duration of sunlight than does the same percentage in April or November, for instance.

In these experiments a rain could operate as a disturbing influence only by increasing an already abundant supply of moisture. Of equal importance with the water supply of plants is the water loss from them. Most of the water loss of plants occurs by evaporation, and its rate depends in part upon surrounding atmospheric conditions. This evaporation was here measured by means of standardized cylindrical porous cup atmometers of Livingston's type furnished by the Plant World. Atmometer readings were obtained at every visit to the stations, about once each fortnight in each case, and all readings were reduced to standard values for comparison, by correction to Livingston's standard cylindrical atmometer.[5]

EXPERIMENTS AND RESULTS.

The results of this study are not yet all computed, but the methods of procedure and the kind of results secured can be best set forth by concrete examples for a single plant form and for the two stations having the greatest differences in climatic conditions. The relation between the dry-weight production of soy bean plants grown one month from seed, and the observed weather conditions. at Easton and at Oakland will alone be presented here These two stations are in extreme locations. The Easton station on the eastern shore of Chesapeake Bay, the low flat coastal plain, has a mild, equable climate, with a small daily range of temperature. The Oakland station, on the other hand, upon the gently rolling tableland at the summit of the Allegheny Mountains, 2,500 feet above sea level, is on a moderate south slope near the bottom of a shallow stream bed. It has a more rigorous climate than Easton, with a rather large daily range of temperature.

A comparison of growth rates of a single species during a single season does not, of course, furnish a sufficient basis for a general comparison of local differences in climate between two localities, and this phase of the problem can not as yet be discussed. The present paper will therefore deal mainly with comparisons of the seasonal differences in growth of soy bean plants at the two stations, and of the climatic conditions under which these differences developed.

The production of dry matter (solids) in soy bean stems and leaves is used here as a measure of growth, as it appears most nearly to sum the results of all the processes of plant nutrition. Growth in height, leaf area, green weight, etc., are at least partly dependent on the amount of swelling due to imbibed water and resulting turgor conditions in the plant tissues, but water is surely not as important a component in the final yield of the plant as is the amount of dry material accumulated. This latter is quite accurately gaged by measuring the resulting dry weight.

The results of these measurements, expressed in graphic form, are shown in figures 1 and 2. The ordinates of the graphs are values of the different weather and plant data, and the abscissæ represent time and season, being the dates of harvest of successive cultures. Thus each graph shows the successive values of a single index as it varies through the season. All of the data of a single station are assembled in one set of graphs, those of figure 1 referring to Oakland, where 8 cultures were harvested, and those of figure 2 to Easton, where 12 cultures were harvested. All values have been reduced to a day basis. The age of each culture when harvested was approximately four weeks, but the growth periods of the successive cultures overlap so that one was harvested about every two weeks. The average daily growth rates of the different cultures, in milligrams of resulting dry weight, are shown by the lowest graph as points whose abscissæ are the dates of harvest. A horizontal line extending to the left of each point represents the length of the growth period for each culture. All the remaining data are computed as aver-

[5] Livingston, B. E., A rotating table for standardizing porous-cup atmometers, Plant world, 1912, 15: 157–162.

Atmometry and the porous cup atmometer, Plant world, 1915, 18: 21–30.

Atmospheric influence upon evaporation and its direct measurement, to appear in MONTHLY WEATHER REVIEW, March, 1915.

ages for periods corresponding to the culture periods. Rainfall is expressed in terms of depth in fractions of a centimeter per day; soil moisture is expressed as a percentage of the dry weight of the soil; evaporation is expressed as cubic centimeters of loss from Livingston's standard atmometer; sunshine is expressed as the number of hours of sunshine per day; and temperature is expressed as the average daily mean temperature [½(max. + min.)] in Fahrenheit degrees. Each climatic factor is thus

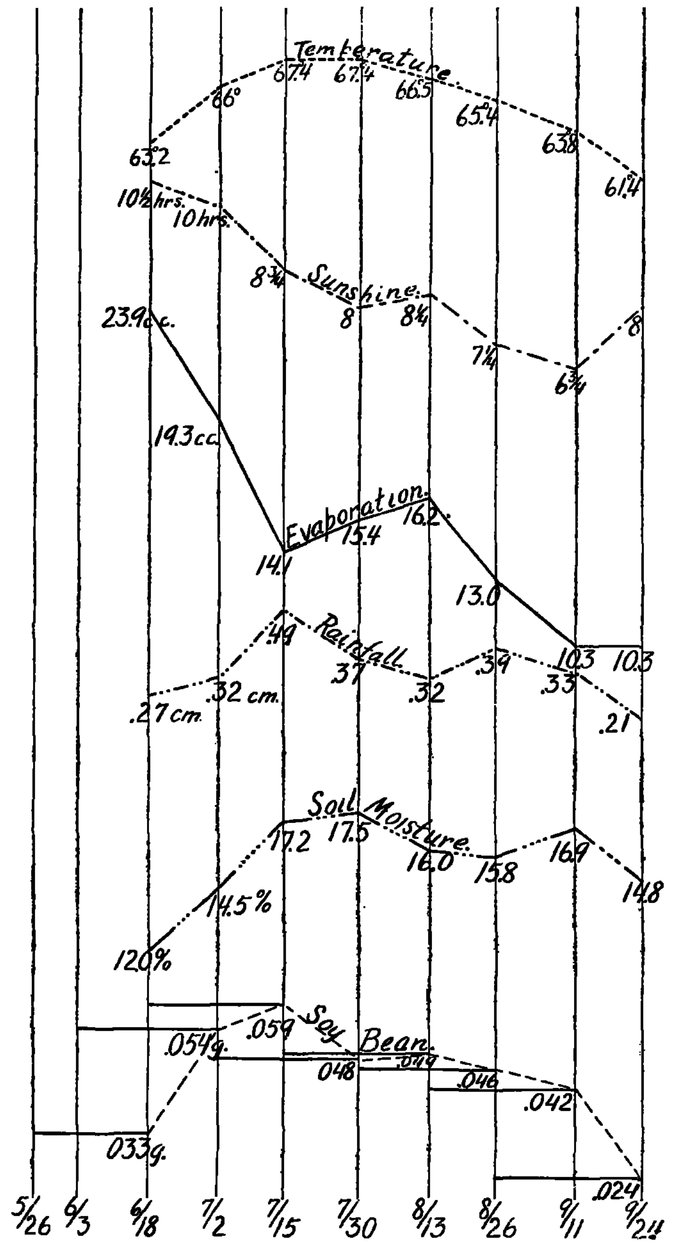

FIG. 1.—Environmental conditions and growth in dry weight of soy bean, Oakland, Md., 1914. Temperatures F.; evaporation from Livingston's atmometer in cubic centimeters.

measured in its own kind of unit. It is obviously impossible to express these incommensurable magnitudes in the same unit or in units that are in any way related. By expressing all the magnitudes of each single graph in terms of the actual magnitude shown for some given period, the same period being thus used as a basis for the reduction of all graphs, the slopes of the graphs might be rendered comparable, but this mode of treatment has not appeared requisite here, except in two cases which will receive attention below. Comparisons between these graphs are to be made only with respect to the times of occurrence of maxima and minima, and with respect to the relative directions of their slopes, whether upward or downward.

The averages here employed do not, of course, bring out the extreme fluctuations in conditions which were recorded. While it is possible, and indeed very probable, that the extremes of conditions within the growing season may frequently affect the plants in a marked manner, yet the method of arithmetical averaging here used is the simplest and most direct form of treatment, and it seems best adapted to a preliminary study such as this. More

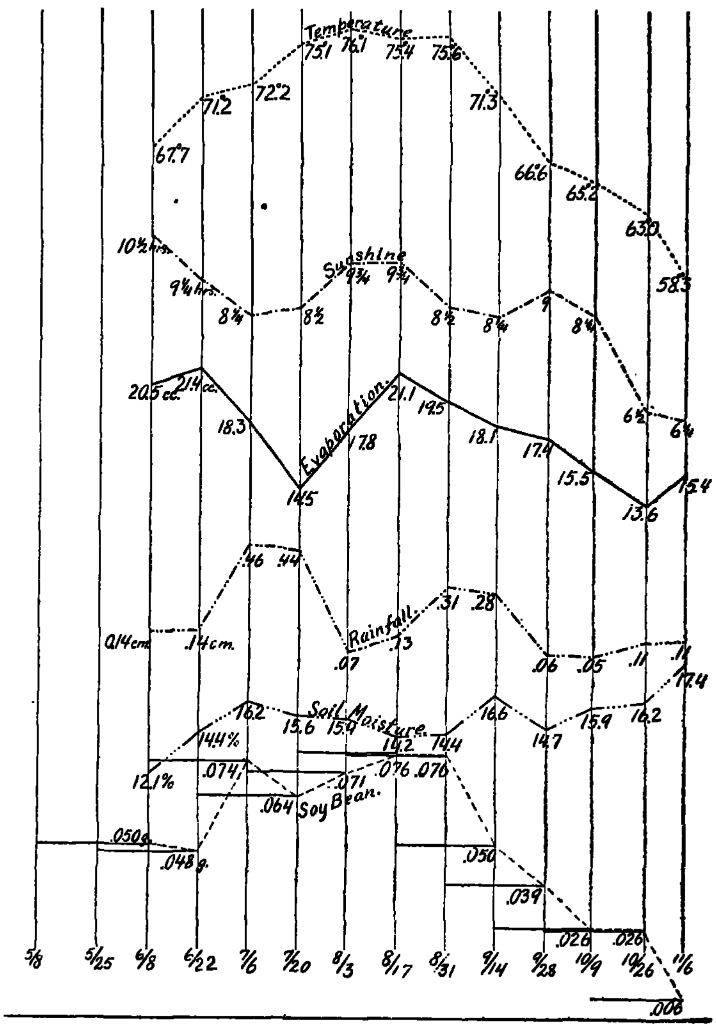

FIG. 2.—Environmental conditions and growth in dry weight of soy bean, Easton, Md., 1914. Temperatures F.; evaporation from Livingston's atmometer in cubic centimeters.

refined treatment of the data, taking account of the interdiurnal and diurnal variations of temperature, etc., is not yet justified.

The most evident features of both series of graphs in figures 1 and 2 are the increasing growth rate of the plants in the spring and the decreasing rate in the autumn. For Oakland the growth rate follows an almost uniform seasonal curve, rising to a crest between the middle of June and the middle of July. For Easton the seasonal relation is less regular, there being a depression of the rate in early July while the crest is reached in August, but the same general relation to season is evident for both stations.

Each point on these two graphs of dry-weight increment represents a distinct culture and a separate lot of plants. Each culture consisted of from three to six plants, with an average number of five. These are all weighed in bulk, so that variations in the dry weight of different individuals of a culture can not be ascertained. Various other measurements of growth showed, however, a general agreement with those of dry weight, and from the former measurements it is possible to get an idea of the range of individual variation between the plants in a single culture. For example, the average leaf length in each individual plant at the age of two weeks exhibited a mean deviation from the average, among individuals of the same culture, ± 11 per cent. Since there appears to be a close relation between the two plant dimensions, average leaf length and total dry weight of stems and leaves, it is perhaps safe to suppose that the individual variations in dry weight within the same culture may have been of about the above magnitude.

Whether this assumption is really justified or not, the individual variations are so small are so small that it seems improbable the averages for the cultures might be very markedly affected by them. It seems safe, therefore, to consider the marked seasonal variations in growth, as indicated by the dry weights per culture, were related to climatic conditions rather than to unknown conditions bringing about individual variations among the plants. These seasonal variations in growth of soy bean plants show a range from 0.024 to 0.059 gram for the Oakland station and from 0.006 to 0.076 gram for Easton.

Considering the latitude of Maryland, which lies between 38° and 39° 45′ N., and its humid, coastal climate with the rainfall normally distributed rather evenly throughout the year,[6] the sunlight intensity and temperature should suffer the most important seasonal changes. The summer of 1914 was rather dry, but this fact does not appear to have influenced the dry weight production here considered. The graphs of rainfall, soil moisture, and evaporation show no apparent direct relation to the seasonal changes in the growth rate. The main effect of rain upon plant growth, as this would occur in the field (that is, the influence of increased soil moisture at times of rain and that of drought during longer periods without rain) was not met with in these auto-irrigated cultures. As would be expected, therefore, the graphs show no apparent relation between the seasonal variations in growth rate and the observed variations in either soil moisture or precipitation.

Neither does the graph of evaporation exhibit any observable parallelism to the graph of dry weight; apparently the plants were so well supplied with water at their roots that the comparatively slight variations in this condition as here shown, were without sensible effect upon the rate of production of dry substance. Likewise, there is no discoverable relation between the number of hours of sunshine and the dry weight. It is to be noted that the sunshine graphs in figures 1 and 2 do not show any seasonal trend.

Temperature.—The remaining climatic influence here to be considered is temperature, which is quite different from the others just mentioned in that there appears to be an unmistakable relation between its intensity and the recorded growth rates at both stations. For Oakland this relation is very evident (see fig. 1); the maxima of both graphs coincide, as do also their minima, and the general direction of slope is the same for both graphs. The only very apparent discrepancy between these two graphs occurs in the case of the culture harvested on July 30 (column 7/30 in fig. 1), when the average daily mean temperature was the same as in the preceding culture, but the growth rate fell from 0.59 gram to 0.048 gram, a decrease of 19 per cent. This decrease is perhaps to be attributed to some unknown influence, perhaps to some other climatic condition, or to a less equable variation of temperature in the latter case.

For Easton (fig. 2) the relation between mean daily temperature and soy bean growth is less consistent in some respects, but there is the same general agreement here as at Oakland. The highest growth rate occurs with high temperatures, from the middle of July (7/20 in fig. 2) to the last of August (8/31 in fig. 2), and the descent from this to the end of the season is quite regular for both mean temperature and growth rate. In the early part of the season there are three apparent discrepancies. The temperature rises from the first to the second period (6/8–6/22), while the growth rate falls. Also, in periods 4 and 5 (7/20 and 8/3), at the highest temperatures the growth rate falls off. Thus, while there is a general agreement between the average daily mean temperatures and the growth rates, these two groups of data disagree somewhat in four of the twenty cultures grown at the two stations. The information at hand is not sufficient to attempt an explanation of these discrepancies at present.

The plotted graphs in figures 1 and 2 assist in comparing the general trend of the different elements as they vary through the season, but they do not permit us to compare the slope values because they are necessarily plotted on different scales and the units are not commensurable. To make them comparable, they may be reduced to terms of a common unit by stating them in percentages of the values of some single period taken as a basis. For this purpose the temperature and the dry weight for period 6 (8/31 of fig. 2) at Easton are taken as the respective unities, as this period shows the highest growth rate at Easton. It is clear at once that the zero of the growth rate does not at all correspond to the zero temperatures of the Fahrenheit thermometer scale, and therefore one or both of the two series of data must be so modified as to make the two starting points as nearly simultaneous as possible. Various investigations have shown that growth ceases in many plants when air temperatures are between 40° and 43°F. Therefore, 40°F. may be tentatively considered as the point on the Fahrenheit thermometer scale corresponding to the zero of plant growth. By subtracting 40 from each daily mean temperature as given in figures 1 and 2, the respective remainders may be taken as the "effective temperatures"[7] as far as growth is concerned. This simple subtraction seems to be here permissible, since the daily mean temperatures during the season here dealt with were never below 40°F. This method is somewhat similar to that frequently employed by phenologists, of summing the daily mean temperatures above a certain temperature value, and comparing this to the time required to complete a given growth process. Here, however, rates per day are used, while the phenologists have employed summations for the entire period of observation. Though the writer knows of no experiments upon the relation of temperature to the growth of soy bean plants it appears best to employ the temperature value 40°F. as the zero point here required. The growth of the plants and the corresponding temperatures are computed on the above basis and set forth on the graphs

[6] See B. C. Wallis in this REVIEW, January, 1915, 48: 11–23. — C. A. jr.

[7] This term "effective temperatures" is here used in a sense widely divergent from that recorded in Abbe—"Relation between climate and crops, 1905. (W. B. bull. 36) p. 170.

of figure 3, which are arranged similarly to those of figures 1 and 2.

As was evident in figures 1 and 2, the graphs of effective temperature and dry weight production show the same general trend, this similarity being more marked at Oakland than at Easton. The lowest growth rates occur in the early and late parts of the season, with the lowest temperatures, and the highest growth rates are recorded for the intervening period of higher temperatures. Another point not shown at all in figures 1 and 2 is here clearly brought out: While the temperature graphs for Oakland and for Easton are roughly parallel each section of the former lies entirely below the corresponding section of the latter, which means simply that the "effective temperature" index for the Oakland station was always lower than the corresponding index for Easton. This difference is by no means constant,

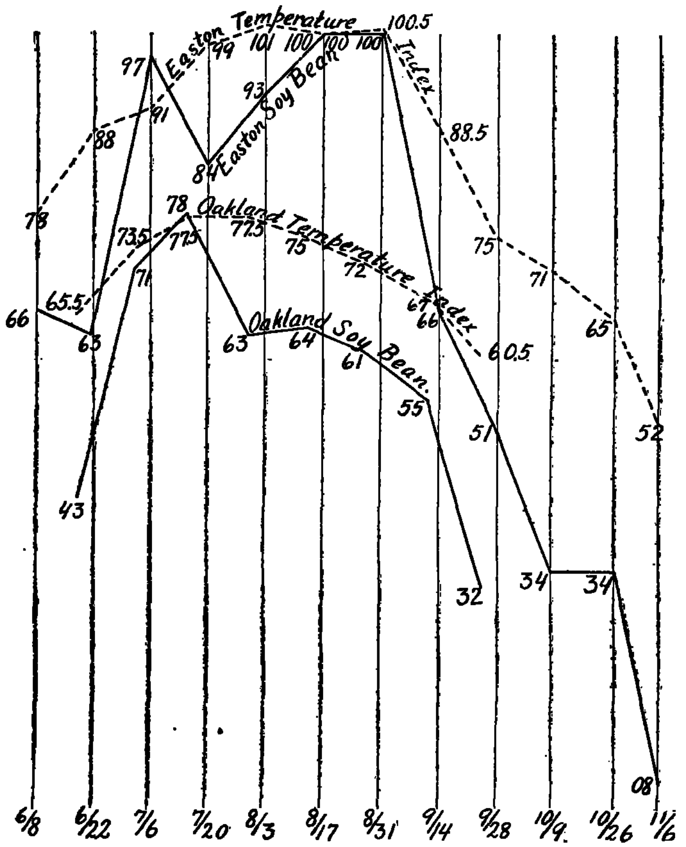

FIG. 3.—"Temperature indices" and growth of soy bean, Easton, Md., and Oakland, Md., 1914.

but has a value of approximately 20 throughout the period common to the two temperature graphs, i. e., following the notation here employed, the temperature efficiency for plant growth at Oakland was, throughout the eight Oakland periods, about 20 per cent (of its value at Easton for the sixth Easton period) less than it was at Easton throughout the corresponding eight periods. For these eight common periods the temperature graph for Easton exhibits values increasing from 88 to 100.5 and then decreasing to 75, while the corresponding march for Oakland is from 65.5 to 75.5 and then to 60.5. It is to be remembered that these magnitudes are all obtained by assuming "temperature efficiency" for growth to be proportional to the temperature above 40°F. and by considering the sixth period at Easton to be 100.

In this connection it is to be noted that the season of observation began one period later and ended three periods earlier at Oakland than at Easton. The early cessation of observations at Oakland was caused by the occurrence of killing frosts at that station. The three additional periods at Easton show a continued decrease in temperature efficiency as here calculated, and the last "index" has a value of only 52, which is 8.5 lower than the last "index" recorded for Oakland. This point illustrates an apparently important feature of the seasonal climatology of these two stations. The station with the shorter frostless season is deficient in total "temperature efficiency," not only on account of generally lower indices but also on account of the premature end of its season while the "index" values are still comparatively high. This does not appear to have been thus emphasized before.

While the general trend and slope direction of the graphs is, on the whole, much the same for the temperature and growth in both cases, as has been noted, yet it is clear from figure 3 that the two graphs are not parallel in the case of either station. In both pairs of graphs the one for dry weight increases in general more rapidly to its maximum region than does that for "temperature efficiency," and it also falls more rapidly after the maximum region is passed. For both stations the growth graph passes somewhat above that for temperature, thus intersecting it at two points. For Easton the two graphs coincide for the sixth observation period, being arbitrarily so arranged, as above stated. An unexplained feature occurs for the fourth and fifth periods of the Easton series, in that the graph of dry weight exhibits an apparently inconsistent concavity upwards in this region. By referring to figure 1, and comparing the graphs of evaporation and of dry weight production of soy bean plants, it appears that this concavity upwards of the graph of the growth rate in periods 4 and 5 corresponds to a similar concavity upward in the graph of evaporation into the air. While this coincidence at least suggests a possible explanation of the behavior of the growth rates in these two periods, the data here presented are not sufficient for a critical discussion of the probabilities. For the present discussion, therefore, this concavity upward will not be further considered.

The general lack of parallelism between the two graphs of each pair (that is, the difference between the slope values or rates or rise and fall) in figure 3 seem to indicate that the higher temperatures were relatively more efficient in producing dry weight material in these plants than were the lower ones. Thus, for Easton, a "temperature index" of 88.5 (eighth period) corresponds to a relative dry weight of 66 (the ratio of these numbers being about 0.75), while a "temperature index" of 100 (sixth period) corresponds to a "dry-weight index" of 100 (the ratio of these being arbitrarily fixed at unity). This difference between the relative efficiencies, in general, of the higher and lower temperatures appear to be a very real feature of these results, one which is well worthy of further quantitative study. Just what conditions may control it is at present impossible to decide, but it may here be suggested that this peculiar relation between the two graphs as here presented may possibly be related to one or more of three different considerations: (1) The assumed minimum temperature for the growth of the plants (40°F.) may be too low for soy bean. This seems somewhat probable, since the indicated growth is so very low with the moderately high temperature of 58.3°F. (Easton, twelfth period). (2) The method here employed for deriving "temperature efficiency" from the mean Fahrenheit temperatures (subtracting a certain number from each of the latter) may not be at all appropriate for other than rough approximations within a narrow range of temperature. This is rendered probable by the studies that have been reported on the "temperature coefficients" of plant growth.[5] (3) Some other environmental factor, besides temperature, may be influential here; if such be the case it appears to be some factor rather closely related to temperatures in its seasonal march, being more effective with high temperatures than with low ones. Such a possible factor is perhaps sunshine intensity, for which, as has been noted, adequate measurements were not available in the present study.

CONCLUSIONS.

While the studies briefly reported above are to be regarded as simply of a preliminary nature, several valuable points seem to have been brought out. In the first place, tests have been made of several new methods of approach to the general problem of relations between plant growth and environmental conditions and these are here recorded. In the second place, some quite tentative but nevertheless apparently important results have been obtained concerning the temperature and other climatic relations between the two particular stations here dealt with.

Perhaps the most important advance in methods here considered is that which involves the employment of like seeds grown in small pots of like soils, for approximately equal and coincident short periods of observation at the different stations. This procedure amounts to the employment of the plant itself as an integrating instrument for (or an indicator of) the effectiveness of the environmental complex as this influences plant growth during such short periods. These plant indicators are, of course, used up in obtaining the summation for each short period, and new plants are started frequently (as though new instruments, *set at zero*, were thus installed) so as to give a continuous series of overlapping integrations. By employing the same soil at the different stations, the influence of soil is at once removed from comparative consideration. In these studies the effect of precipitation upon soil condition (water content mainly) was also removed from consideration by the employment of the auto-irrigator, which effectively prevented the soil masses of the culture pots from ever becoming very dry. Rains raised the soil moisture content considerably above the optimum for longer or shorter periods, but it was never allowed to fall markedly below its optimum. Livingston's cylindrical, porous-cup atmometer was here employed with apparently satisfactory results to secure a measure of evaporation into the atmosphere, as it may affect water loss from plants. The adequacy of daily temperature maxima and minima and daily average temperatures in this sort of work is clearly shown.

In the handling of the various kinds of data resulting from these series of measurements a method which is not new, but which seems not to have been generally employed in this sort of work, has been resorted to, and is illustrated in the foregoing treatment of the relation between temperature and growth. We have deduced average mean daily "temperature efficiencies," or "temperature indices," from the mean daily air temperatures (°F.) by subtracting 40° from the mean, on the rather common phenological supposition that plant growth begins only above 40°F., and that each degree of temperature above this point represents the same increment of "temperature efficiency" for growth. These "indices" were then reduced to terms of the particular "temperature index" that corresponds to the highest growth rate encountered in these two series of observations. Thus the "temperature efficiency" (mean daily temperature *minus* 40) for the sixth observation period at Easton was taken as unity and all other temperature efficiencies (for Oakland as well as Easton) were stated as hundredths of this assumed unit. A similar treatment of the growth rates, using the rate at Easton for the sixth period as unity, brought the growth rates and "temperature indices" throughout into a comparable series. This method allows the "intensity" or "index" of any environmental factor and the rate of any plant process, at any station and for any period, to be expressed in terms of the corresponding index or rate for any other station or period. Thus, for example (see fig. 3), the growth rate for the third period at Oakland is given as 0.78 of the assumed unit of growth rate and the temperature efficiency for the same period is given as 0.775 of a comparable unit, for each represents the degree of divergence of the respective values from the corresponding values at a stated time and place, which are taken as the standard of comparison. By making the units of different features correspond to the same observation period, the seasonal marches of the different features may be directly compared.

The present comparison between plant growth and climatic conditions at Oakland and at Easton, two climatically very different stations, has brought out several at least interesting results, which are to be considered as directly applicable only for the conditions and for the plant form (soy bean) here dealt with, for the summer of 1914. These are summarized below.

With plentiful soil moisture, in a light soil, a range of mean daily precipitation from 0.05 centimeter (0.02 inch) to 0.50 centimeter (0.20 inch), together with a low rate of evaporation (ranging from 10 to 24 cu. cm. per day from Livingston's standard cylindrical porous clay cup atmometer), were without noticeable influence upon the growth rate of soy bean plants in the first month of their developmental history. The growth of these plants was apparently controlled by other conditions than that of water.

Under the conditions here encountered soy bean exhibited a pronounced and somewhat regular march of its growth rate (as measured in terms of the dry-weight material accumulated in leaves and stems during the first month of its growth from seed) throughout the growing season. This rate increased to a maximum in the summer and then decreased. The maximum rate of production of dry matter occurred in the warmest part of the season, and the march of this rate is represented by a graph of about the same general form as that possessed by the corresponding graph of air "temperature efficiency" (considering 40°F. as the physiological zero of temperature for growth). Nevertheless, the slopes of these two graphs, while alike in general direction, proved not to be the same in magnitude; the "temperature efficiency" for the production of dry weight of these plants was shown to be relatively much more effective with high temperatures than with low. This feature suggests either that the method here employed for deducing "temperature efficiency" from temperatures on the Fahrenheit scale may not be feasible for the plant form and for the conditions here dealt with, or that some other condition added its effect to that produced by temperature in the warmer portion of the season. Under the conditions of these tests the growth rate tended to vary almost directly with the "temperature index" when the air temperatures were low. With high air temperatures the growth rate

[5] Lehenbauer, P. A., Growth of maize seedlings in relation to temperature. Physiol. researches, 1914, 1:247-288.

was relatively much greater than can be accounted for by the "temperature indices" alone. The agreement in this regard, between the data from the two very different stations included in these studies, seems to suggest that this feature may be general for a considerable range of conditions, at least for the plant form here considered.

With the given soil and soil moisture content the intensities of evaporation experienced by these soy bean plants were apparently not sufficiently high seriously to overtax the process of water absorption or that of water conduction. Had the possible rate of water supply to the roots been sufficiently diminished, had the rate of evaporation into the air been sufficiently increased, or had both of these alterations occurred together, then the water relation should have had a more pronounced influence upon the growth rate. It might, indeed, have obscured the effects of the temperature relation. As the experiments were carried out, however, the seasonal changes in temperature were apparently much more important in the control of growth than were the changes in any other measured condition or conditional complex.

A comparison of the seasonal march of the growth rate for Oakland with the corresponding march for Easton brings out three important considerations. (1) Neglecting an unexplained and temporary fall in the rate, shown for the fourth and fifth periods at Easton, the graphs representing these two seasonal marches have much the same general form, but the top of the Easton graph appears flat, while that for Oakland rises to a definite maximum, and then rapidly falls. (2) As is clearly depicted in figure 3, the growth rates of the Oakland series are markedly less than the corresponding ones of the Easton series, these quantities being rendered strictly comparable by stating all of them in terms of the growth rate for the sixth period at Easton considered as unity. In general, the Oakland rates are found to be from about 10 to about 20 per cent or more (on the basis of the assumed unit) lower than the corresponding rates for the other station. (3) The early occurrence of frost at Oakland brought the season to a close earlier than was the case at Easton, and the last growth rate for the latter station is shown as markedly lower than any encountered at Oakland. The principle here brought out is worthy of considerable emphasis. For a short frostless season, characterized by a great daily range of temperature, the lowest growth rate may be generally expected to be higher in value than the lowest rate for a longer frostless season, with more equable temperatures.

NEW ZEALAND RAINFALL IN 1914.

By Rev. D. C. BATES, Director.

[Dated: Dominion Meteorological Office, Wellington, New Zealand, Feb. 17, 1915.]

The year 1914 will long be remembered as one of the most trying ever experienced by the farmers and pastoralists of New Zealand. The winter months (June, July, and August), proved mild, and the rainfall, compared with the averages for previous years, was generally deficient. This dry season was followed by an exceptionally dry spring, but added to this was a summer in which greater quantities of rain were much needed. Though "absolute droughts," in a technical sense, were rare, and absolute minimum monthly rainfalls were not made in any long records of stations, such a continuation of dry conditions was distressing, and such a succession of dry seasons had not previously been regarded as possible in the Dominion. Month after month the total rainfalls were below the averages for the month in previous years in most parts of the Dominion, but it is remarkable that in Southland conditions were almost reversed, and heavy and frequent rains were there experienced during the year. In the South Island the monthly means for previous years show a fairly even distribution of rainfall throughout the whole year; but winter is the rainy season of the North Island. Such was not the experience in 1914, and the leading meteorological feature which accounts for it is the absence of ex-tropical disturbances of a cyclonic character and a counterbalancing prevalence of "brave" westerly winds which held sway during the greater part of the dry period.

Occasionally while Australia has a "dry time" New Zealand has abundant rainfalls, but both suffered in 1914, and it is noticeable that reports from England and France indicate that a somewhat similar and remarkable succession of months of deficient rainfall was experienced in other parts—in England and France at least. Other regions may also disclose irregularities in the precipitation of the world, and when these can be properly compared and studied it is possible that men may recognize reciprocal relationships and trace common cosmical causes which are as yet unknown.

Scattered over the globe are thousands of observers who carefully and patiently, and in the vast majority of cases voluntarily, record the rainfall of their neighborhoods. The cumulative results of their humble devotion to science must undoubtedly prove of great value to their own immediate localities and the countries they inhabit, but the fruits of their observations may, it is hoped, reach a much higher appreciation in the future when more is known of the laws governing precipitation. Rainfall, it may be remarked, is now the least certain element, although the most important item in weather forecasting.

The following table has been computed to show the percentages of rainfall compared with the monthly averages at select stations during the several months of the year in various parts of New Zealand.

TABLE 1.—*Monthly percentages of average monthly rainfalls at selected stations in New Zealand during 1914; number of months having falls above (+) and below (−) their respective averages; and the total annual falls for 1914.*

Place.	January.	February.	March.	April.	May.	Winter. June.	Winter. July.	Winter. August.	September.	October.	November.	December.	Months above or below average. +	Months above or below average. −	Total rainfall for year 1914.
NORTH ISLAND.															Inches.
Auckland	51	56	77	124	106	71	81	28	40	32	44	61	2	10	28.42
Te Aroha	39	35	137	149	59	45	55	29	25	25	37	69	2	10	31.98
Rotorua	22	56	69	145	49	62	70	18	44	27	24	53	1	11	29.70
Tauranga	28	26	110	188	42	35	42	9	31	23	16	48	2	10	30.66
Gisborne	22	59	176	90	236	56	14	80	19	23	36	9	2	10	38.71
Greenmeadows, Napier	14	62	111	101	137	6	4	38	14	8	56	21	3	9	22.12
New Plymouth	80	75	43	128	74	33	50	28	29	46	120	122	3	9	39.79
Moumahaki, Waverley	53	133	23	131	154	81	66	45	45	64	80	94	3	9	38.38
Palmerston North	120	78	34	140	130	63	54	57	34	51	95	124	4	8	33.22
Taihape	65	145	65	86	136	63	81	30	33	34	58	71	2	10	31.71
Masterton	56	91	67	133	151	76	26	33	41	18	62	78	2	10	28.17
Wellington	79	56	68	64	166	76	43	25	36	37	59	60	1	11	31.90
SOUTH ISLAND.															
Hokitika	141	78	33	134	96	56	86	66	88	58	191	134	4	8	112.32
Nelson	36	112	54	171	110	75	91	18	9	17	*100	64	3	9	26.01
Christchurch	65	57	44	125	162	99	18	44	37	61	108	110	4	8	19.90
Lincoln	104	86	57	124	189	82	18	25	30	81	98	106	4	8	20.95
Timaru	119	159	107	90	125	28	13	54	8	33	113	65	5	7	17.99
Waimate	178	192	132	166	93	70	18	35	17	53	90	76	4	8	23.14
Dunedin	106	114	59	124	81	88	69	24	62	60	107	111	5	7	31.31
Gore	166	172	36	128	151	163	169	116	123	99	215	114	10	2	38.89
Invercargill	132	85	17	126	91	141	97	144	152	101	116	117	8	4	49.58

* Was a fraction below the mean.